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FINAL REPORT ON CGRO/BATSE OBSERVATIONS OF MAGNETOSPHERIC ELECTRON MICROBURSTS

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ABSTRACT

We used the very high-time resolution and remote-sensing capabilities of CGRO/BATSE to conduct a preliminary analysis of bremsstrahlung X-rays from magnetospheric electron microbursts triggered by powerful VLF transmitters. Previous observations of these microbursts have been apparently only been obtained from balloon-borne X-ray detectors and in situ spacecraft measurements of precipitating energetic electrons. These precipitation microbursts, typically of 0.2-1.2 s in duration, are thought to be the result of a gyroresonant interaction of the trapped electrons with electromagnetic waves, which at this time are identified primarily injected by ground VLF transmitters[e.g., Datlowe and Imhof,1990]. For this project, we initiated the first studies of CGRO/BATSE *remote* atmospheric X-ray observations with the following rather promising preliminary results: (1) Occurrence frequency histograms of X-ray burst durations for these events, as detected by BATSE, indicated typical microburst durations in the range 0.2-1.2 s; these events were further analyzed on an individual basis with some events showing significant microburst activity while other X-ray events were smooth and consistent with very little microburst content; (2) A burst location algorithm allowed fairly precise latitude/longitude determinations for remote bursts, with indications of bursts associated with transmitter sites not necessarily accessible to insitu measurements; and (3) Perhaps most exciting, we found that ultra-high time-resolution profiles of some events clearly show defined bursts of about 10 ms duration, and possibly shorter, with possible periodicities of 50-100 ms.

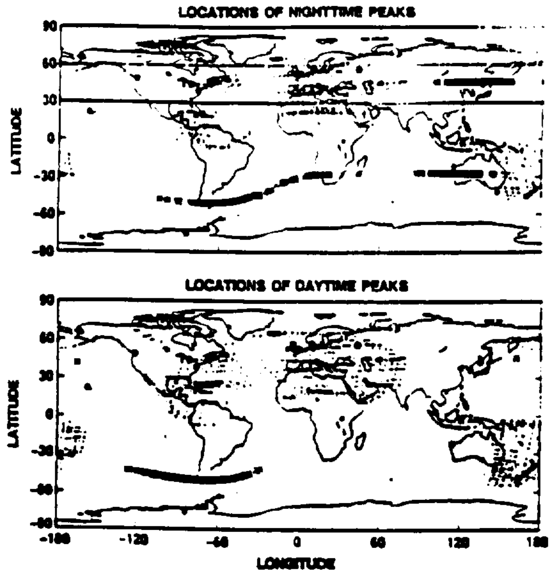

Figure 1: Map of electron cyclotron resonance peaks(asterisks) observed with the SEEP spacecraft, with major transmitters indicated by solid circles[Datlowe and Imhof, 1990]

INTRODUCTION

Microbursts of magnetospheric electrons precipitating into the atmosphere are characterized as short duration(<1 s) impulses of enhanced fluxes, typically in the auroral or sub-auroral zones. The most widely reported microburst events appear to be those with characteristic spectral e-folding energies of 25-50 keV and durations of about 0.5 seconds[e.g., Rosenberg et al.,1990]. These have been observed primarily with X-ray detectors on balloons and rocket-borne parachute deployments[e.g., Rosenberg et al.,1990; Bering et al., 1988] as well as direct electron measurements from satellites[e.g., Oliven and Gurnett,1968]. These types of events are generally thought to be precipitation of trapped electrons induced by gyroresonant interactions with a burst waveform of ELF/VLF chorus causing pitch angle scattering into the atmospheric loss cone. This interaction probably occurs near the magnetic equator[Rosenberg et al.,1990; Roeder et al.,1985] at least for those microbursts occuring near magnetic shells near L=4. Rosenberg et al.[1990] suggested that for microbursts with short(0.2-0.6 s)durations, the electrons precipitate directly into the atmosphere after the pitch angle scattering interactions, while the longer duration(0.6-1.2 s) bursts are produced by electrons which mirrored in the conjugate ionosphere before precipitation.

Very recently, Datlowe and co-workers have utilized *insitu* energetic electron measurements at very low altitudes[Datlowe and Imhof, 1990] and from CGRO/BATSE[e.g., Datlowe et al., 1995] to examine events of intense inner radiation belt energetic electron precipitation and their relationship to VLF transmitter sites. These studies point to a strong coincidence of these events with such transmitter sites, particularly at nighttime. Figure 1, from Datlowe and Imhof[1990], shows detection of cyclotron resonance peaks in the energetic electrons on a world map projection, together with locations of known powerful VLF transmitters. The close association of resonance peaks with at least two known transmitters, one in the north and one in the south, is evident in at least the nighttime panel.

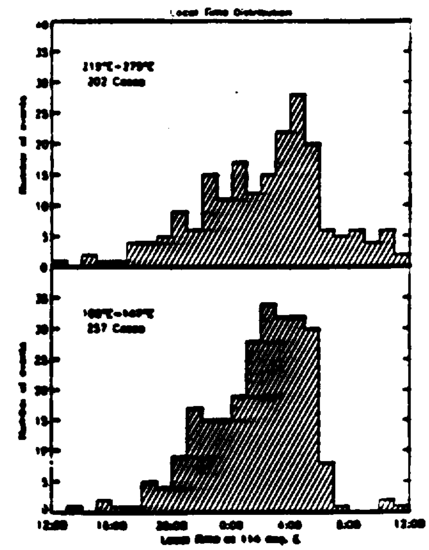

Figure 2: The number of times BATSE recorded insitu measurements of electrons in quasi-trapped orbits versus the local time at the indicated longitude ranges when the cyclotron resonance interaction is calculated to have occurred for a particular transmitter at 114° E longitude[Datlowe et al., 1995].

Figure 2, from Datlowe et al.[1995] using CGRO/BATSE, displays occurrence histograms vs. local time of BATSE recorded energetic electrons for two longitude ranges. The events are almost entirely restricted to the nighttime for the 100-147°E longitude range, and are highly peaked in the nightime for 219-275°E longitude. Datlowe et al.[1995] conclude that the concentration of events in the nighttime is associated with the efficient transmission of the VLF waves from the transmitter through the low-density dark ionosphere into the radiation belts where the wave-particle interaction and consequent electron precipitation takes place.

Our preliminary study for this project(next section) complemented those mentioned above by beginning to utilizing algorithms for the remote sensing and very high-time resolution of burst profiles to probe important aspects not available for example in the simple event frequency studies of Datlowe et al.[1995].

PRELIMINARY STUDY RESULTS

CGRO was launched on April 5 1991 into a nearly circular orbit at 450 km altitude at 28.5° inclination. It carried a complement of 4 instruments, including the Burst and Transient Source Experiment(BATSE) [Fishman et al., 1989].

BATSE consists of eight large area detectors (LAD's), 2025 cm^2 in area, placed on the spacecraft so that their surfaces are parallel to the faces of an octahedron centered over the GRO spacecraft. This geometry provides a continuous monitoring capability for all possible source directions. In addition there are eight smaller spectroscopy detectors positioned similarly to the LAD's. Data from all these detectors were used in the preliminary analyses presented here.

In this section, we present results substantially involving the application of ultra-high-resolution burst time-profile and location determination algorithms to the BATSE data during periods when anistropic X-ray fluxes were determined to be coming from energetic electrons precipitating into the Earth's atmosphere. We utilized an algorithm which has been developed to identify real emission peak structures in flux time histories(e.g., microbursts). The algorithm was first presented at the November 1994 AAS High Energy Astrophysics Division meeting in a gamma ray burst analysis application and will be included in a manuscript soon to be submitted for publication[Pendleton et al., 1996]. Basically, the algorithm searches through the flux history identifying intervals where the flux rises by 4σ in significance above a particular base level and then falls back to that base level. The analysis is performed on background subtracted source data for a range of flux base levels spaced $\frac{1}{3}\sigma$ apart from the lowest point in the source flux to 4σ below the highest point in the flux. The durations of emission peaks that showed no additional significant peak structure within the intervals spanned by their base points were then tallied for each data set analyzed. The burst duration was calculated as the full width half maximum of the peaks for appropriate comparison to the X-ray microburst duration obtained over Siple by Rosenberg et al.[1990]. Since this technique is not disabled in regions where microbursts cluster together, durations of clustering microbursts as well as isolated microbursts are obtained and presented.

Using the signal criteria and selection algorithm described above, the occurrence frequency or percentage of microburst durations for nine separate events both before(dotted line) and after(solid line) background noise(dashed line) is subtracted are calculated and shown in Figure 3a. The histogram of background noise is built by using the same algorithm over a large number of data intervals in which there were no physical sources, and thus represents the algorithm's measure of background statistical fluctuations.

We see that the detected microburst durations cluster in the 0.2 to 1.2s range, which is generally similar to the occurrence frequency distributions observed in balloon-detected X-ray microbursts over Siple by Rosenberg et al.[1990], which is displayed in the right panel(Figure 3b). It would have been interesting with the improved microburst time resolution of BATSE and the opportunity to sample events associated with different transmitters/L-shells to see whether there would have been differences in such histograms when we separated the events according to nearby transmitter site and other possible dependences.

In Figure 4, we show five event location determinations, for five of the 64ms resolution microburst events we have analyzed, on a world map similar to that of Figure 1. These locations were determined from a variant of the BATSE gamma-ray burst location algorithm[cf. Pendleton et al., 1992]. This algorithm projects the event location from the spacecraft down to the calculated altitude of atmospheric penetration for electrons corresponding to the X-ray energy channel used[e.g., National Academy of Sciences, 1964; Zombeck, 1982]. Continuing refinement of this algorithm, including the projection of location error circles onto the Earth's surface, can be quite useful for interpretation of the various types of events originating in the Earth's atmosphere, including Terrestrial Gamma Flashes. This last category of events, conversely, could be used in certain instances to provide a means of independently ascertaining the accuracy of the burst location algorithm.

The filled circles in Figure 4 show the positions of some VLF transmitters, with space-

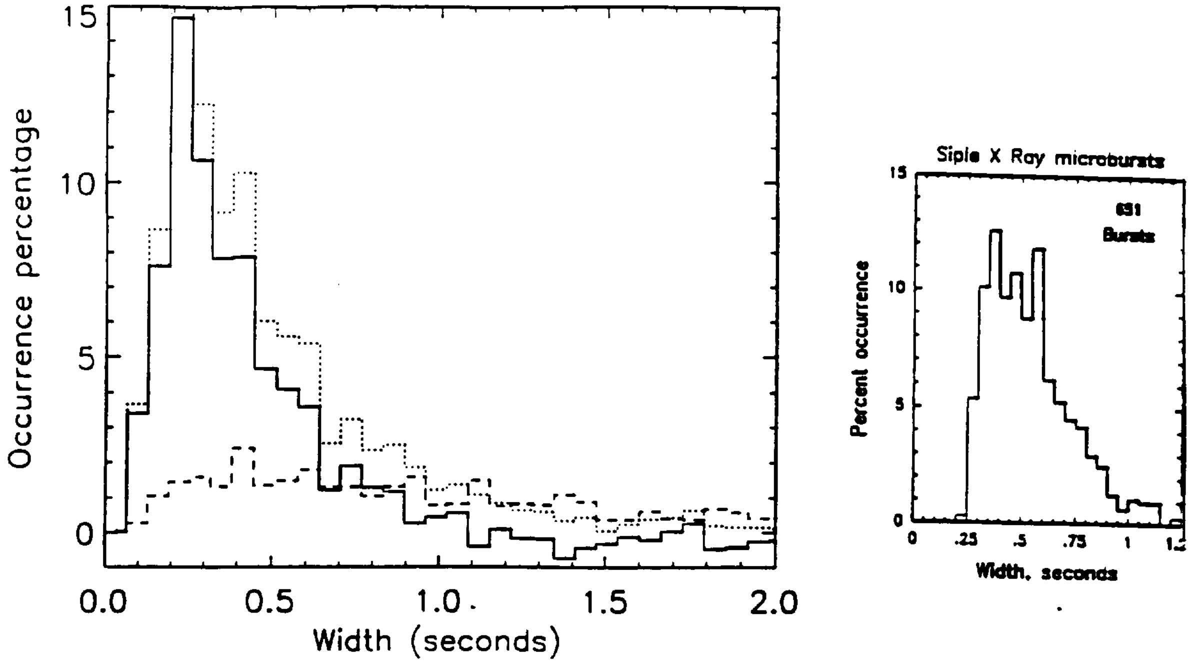

Figure 3: A percent occurrence frequency histogram of atmospheric X-ray microburst durations with 64ms time resolution, for microbursts detected during nine overall events by BATSE(left panel). Right panel shows broadly similar histogram for balloon measurements of X-rays over Siple[Rosenberg et al., 1990]

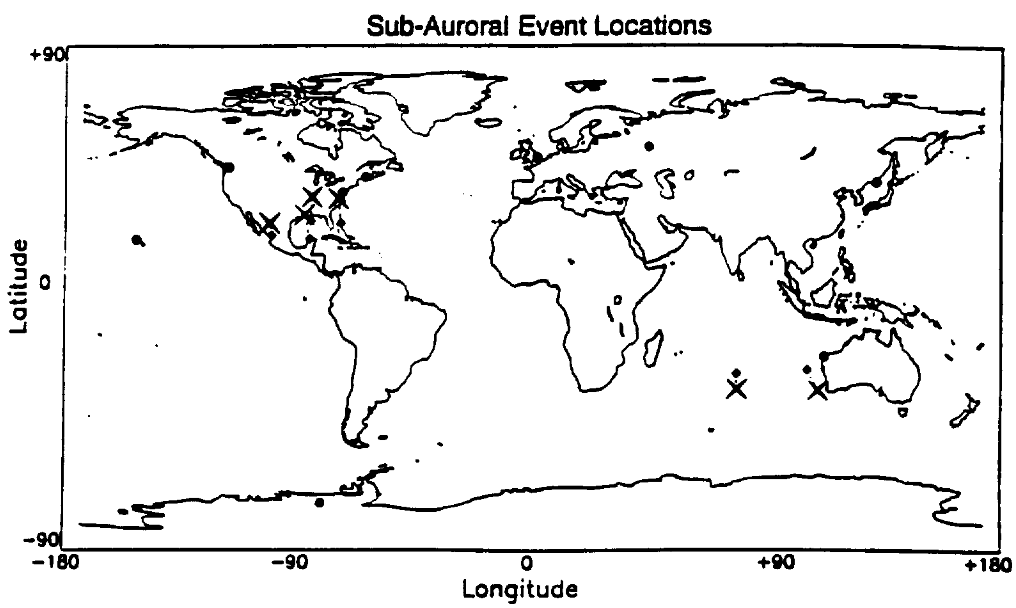

Figure 4: Spacecraft locations for 5 BATSE-detected bursts(diamonds) and the projections to the atmospheric source location(four-point stars) on a world map with some VLF stations(filled circles).

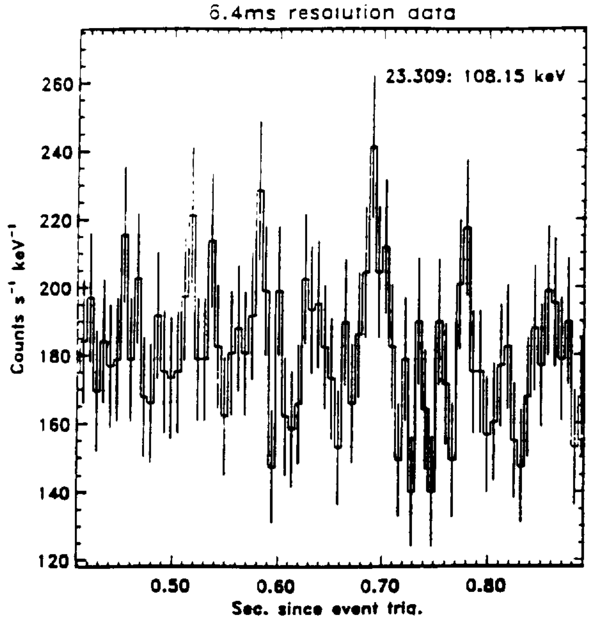

Figure 5: An ultra-high-resolution time profile of 0.6 of 25-100 keV channel countrates.

craft locations and projected burst locations indicated by diamonds and four-point stars, respectively. The events located in this analysis so far seem to be closely coincident with the transmitter locations as indicated by the circles. In addition, these events occur over regions of the Earth where the electron mirror points are below 100 km[Datlowe and Imhof,1990]. For such low mirror points, electrons are lost quickly to the atmosphere and would be much more rarely observed with insitu measurements[Datlowe and Imhof,1990]. However, studies along the lines we have begun could have extended the investigation of transmitter-triggered magnetospheric precipitation to regions not sampled or missed with the insitu measurements. The relatively large earth surface coverage from the spacecraft location(approximately 1000 km in radius) for BATSE's detection of these events would have allowed for a detected event rate which would have been more than sufficient for several detailed analyses and correlations.

Exploration of the ultra-high-time resolution capabilities of BATSE microburst detection for understanding these magnetospheric microbursts was also begun. Figure 5 shows 0.6 seconds of countrate data in the approximately 25-100 keV channel during an event whose location appeared to be closely associated with the transmitter NSS, which is at 39.0^o N latitude, 283.6^o E longitude, at L=2.68(cf. Table 1 of Datlowe et al.[1995]). These data are plotted at 6.4 ms resolution with 1 σ bars indicated(if warranted, at least 0.1 ms resolution data is available). In Figure 5 we clearly show defined bursts of about 10 ms duration, and possibly shorter, with possible periodicities of about 50 and 100 ms.

For comparison, we note that the bounce period for particles of equatorial pitch angle α_o is given by [e.g., Roederer, 1970]

$$\tau_b = 4\frac{R_E}{c}Lf(\alpha_o)\beta^{-1}$$

where the function f(α_o) can be approximated for $\alpha_o = 40 - 90^o$ as

$$f(\alpha_o) = 1.30 - 0.5 sin(\alpha_o)$$

The energy channel is 25-100 keV, and using a representative energy of 60 keV for the electrons yields $\tau_b = 0.5$ seconds, so if the periodicities are real they would correspond approximately to quarter and eighth electron bounce times. Clearly, further analysis is required in understanding such high-resolution countrate profiles.

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